NATIONAL SUMMARY: ENVIRONMENTAL PRESSURES

In general, there are two types of environmental pressures on reefs (or any ecosystem) – natural forces and human impacts. Natural forces have shaped the distribution of coral reefs over the ages. A broad range of temperature and sea-level changes occur over hundreds and thousands of years. Diseases, storms, and predation are more intense but have shorter-term impacts.

On top of natural forces, human-induced pressures come from a myriad of activities (A. Bentivoglio pers. comm.). These include the following.

- Coastal development with the resulting runoff and sedimentation
- Chemical water pollution (toxic contaminants and nutrient enrichment)
- Over-harvesting of fishery resources and destruction of reefs and associated habitats
- Direct harvest of coral colonies and live reef fish
- Ship and boat groundings and anchor damage
- Tourism and recreation
- Alien invasive species
- Marine debris

Every coral reef ecosystem under U.S. jurisdiction has suffered from human disturbance to some degree. Because they are close to population centers, portions of reefs off Florida, Puerto Rico, the USVI, the Main Hawaiian Islands, Guam, and the CNMI have been degraded by multiple environmental and human-induced stresses. In contrast, the Flower Garden Banks National Marine Sanctuary, Navassa Island, the remote Pacific Island refuges, and the NWHI, have few human-induced pressures and remain relatively pristine. Table 2 compares the environmental threats to coral reef ecosystems as perceived by over reef 60 managers from the United States and Pacific Freely Associated States[51].

Adding human pressures to natural variability may degrade local reef ecosystems faster. Given time, corals and reef communities mostly recover from **acute** (short-term and often dramatic) natural

Table 2. Summary of concerns about natural and anthropogenic pressures on coral reef ecosystems in the United States and Pacific Freely Associated States (Source: Priorities of reef managers for the United States and Freely Associated States).

	Atlantic/ Caribbean				Polynesia			Micronesia					
	Florida	Puerto Rico	U.S. Virgin Islands	Flower Gardens	Main Hawaiian Islands	Northwestern Hawaiian Islands	American Samoa	Guam	Northern Mariana Islands	Marshall Islands	Federated States of Micronesia	Palau	U.S. Remote Insular Reefs
Global warming and bleaching	H	M	M	L	L	L	M	L	M	H	M	H	M
Diseases	H	H	H	L	L	L	L	L	L	L	L	L	L
Tropical storms	M	L	H	L	L	L	M	M	M	M	L	L	L
Coastal development and runoff	H	H	H	L	H	L	H	H	H	M	H	H	L
Coastal pollution	H	H	H	L	H	L	H	H	H	L	M	H	L
Tourism and recreation	M	M	M	L	H	M	L	M	M	L	L	M	L
Fishing	H	H	H	L	H	M	H	M	M	M	H	M	M
Trade in coral and live reef species	M	H	L	L	H	M	M	L	L	H	L	L	L
Ships, boats, and groundings	H	M	H	M	H	H	M	M	M	L	H	M	M
Marine debris	M	M	L	L	M	H	L	L	M	L	H	M	M
Alien species	M	L	L	M	H	H	M	L	L	H	L	M	M
Other physical impacts	L	H	L	L	M	L	L	L	H	M	L	L	H
Offshore oil and gas exploration	L	L	L	M	L	L	L	L	L	L	L	L	L

H High concern | M Medium concern | L Little-to-no concern

[51] Information for this table and the basis for conclusions stated in the following subsections are in the regional reports that follow this National Summary.

stresses after the condition abates. However, these stresses may make key organisms more vulnerable to **chronic** (long-term, low-level, and perhaps undetectable[52]) stresses created by human populations (sedimentation, nutrification, overfishing, etc.). Moreover, natural and human stresses may interact **synergistically**, combining substances or factors which separately may be relatively harmless, but when added together can be more potent and magnify impacts in unpredictable ways.

Global Climate Change and Coral Bleaching

All coral reef managers considered global climate change a major, yet largely unmanageable threat to the survival of coral reef ecosystems. Managers from Florida, the RMI, and Palau, however, consider global climate warming and coral bleaching a major threat to their local reefs. Those from Puerto Rico, the U.S. Virgin Islands, American Samoa, CNMI, the Federated States of Micronesia, and the U.S. remote insular reefs considered these factors a medium threat (Table 2).

Figure 42 Majuro, the capital of the Marshall Islands, is a low-lying coral atoll that could be submerged by a rise in sea level (Photo: James McVey).

According to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2001), the 1990s was the warmest decade of the century and 1998 the warmest year on record (1861-2000). In the 1990s, concentrations of greenhouse gases and aerosols reached the highest recorded levels since the pre-industrial era. In its conclusions, the Panel blamed human activities for increasing atmospheric concentrations of key greenhouse gases[53], primarily from the combustion of fossil fuels, agriculture, and coastal development.

This *Third Assessment Report* presents the scientific consensus for changes over the next century.

- Globally averaged, CO_2 concentrations in the atmosphere are projected to range between 540-970 ppm in 2100, more than doubling the pre-industrial age average of 280 ppm and well above the 2000 average of 368 ppm.
- Globally averaged, sea surface temperatures are projected to increase 2.5-10.4°F (1.4-5.8°C) between 1990 and 2100.
- Globally averaged, annual precipitation is projected to increase during the 21st century; regionally, both increases and decreases of 5-20% are projected.
- Global mean sea level is projected to rise by 0.3-2.9 ft between the years of 1990 and 2100, with regional variation.

With confidence, the IPCC (2001) predicts ecological productivity and biodiversity will be affected by climate change and sea-level rise, increasing the risk of extinction for some vulnerable species.

Changes in sea level from long-term climate change, have direct implications for coral reefs, as well as human populations that inhabit islands or shores with little elevation (Fig. 42)[54]. There could be severe social and economic effects, as resources critical to island and coastal populations would also be at risk (beaches, freshwater, fisheries, atolls, and wildlife habitat). Using historical evidence, Shinn (1988) showed changes in reef communities as a result of sea level rise and flooding of shallow inshore bays off southeastern Florida (Florida Key West to Palm Beach).

Increasing concentrations of greenhouse gases are expected to change the frequency, intensity, and duration of extreme events. There will be more hot days, more heat waves, more heavy precipitation, and fewer cold days. Besides inundating low-lying coastal areas from the melting polar ice, potential climate change impacts include increased sedimentation of coral reefs caused by drought followed by heavy rains. The rising sea level could eliminate deeper reefs because the sunlight needed for photosynthesis would be too low.

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[52] For example, chronic sediment stress could be causing the loss of a small percentage of coral cover on near-shore reefs every year that would be undetectable with most of the existing monitoring programs.

[53] Carbon dioxide, methane, nitrous oxide, and tropospheric ozone.

If these predictions hold, then increased damage to shallow-water corals is likely at the physiological level. First, a coral reef is the net accumulation of calcium carbonate from corals and other calcified organisms. The rate of calcification partly determines the growth of the reef. If calcification efficiency declines, reef-building capacity also declines. This could happen with increased atmospheric CO_2 because coral reef calcification depends on saturation of the carbonate mineral aragonite in surface waters. Kleypas *et al.* (1999) predicted that increased CO_2 levels would decrease both the aragonite saturation in the tropics by 30% and **biogenic** (biologically derived) aragonite precipitation by 14-30%. According to these scientists, current atmospheric concentrations of CO_2 have already reduced the average deposition rate of calcium carbonate in the tropics.

Figure 43. Coral bleaching in Guam (Photo: Robert Richmond).

Second, increased surface temperatures and ultraviolet light may cause coral bleaching (Fig. 43) that can kill polyps and entire coral colonies. From models of global climate change, Hoegh-Guldberg (1999) predicted that temperature would exceed the thermal tolerance levels of reef-building corals every year for the next several decades. In other words, coral bleaching at the level of the 1997-1998 global event is likely to be commonplace over the next 20 years.

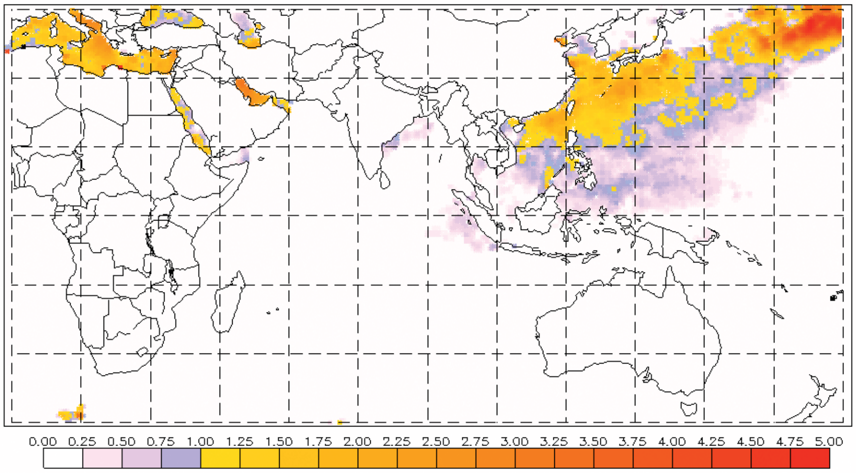
Right now, many corals already live close to their upper temperature limit. These could be bleached with even periodic increases of a few degrees.

Coral bleaching and disease have been documented to coincide with elevated water temperatures associated with El Niño and La Niña events. Worldwide, the worst coral-bleaching episode began in late 1997 during an El Niño event, and continued well into 1998 (Pomerance 1999, Wilkinson 1998). In the Caribbean, it coincided with the hottest summer/fall seawater temperatures on record, affecting extensive areas of shallow-water reefs off Florida, Puerto Rico, and the USVI. In the Pacific, the impact was spotty, but intense. Reefs around Palau, particularly ocean-facing slopes, experienced severe coral bleaching, with an estimated one-third of all corals affected, especially the *Acropora* corals. One area in Micronesia had reefs with 20% of corals bleached to 60 ft, including a wide variety of hard and soft corals. Yet other parts of Micronesia reported only minor bleaching.

Since 1997, NOAA has predicted coral bleaching from surface water temperatures gathered from satellites and *in situ* buoys (NOAA 2001, Fig. 44) and placed the information on their web site (NOAA 2002). NOAA satellite data confirmed that Palmyra Atoll in the U.S. Line Islands experienced temperatures over 86°F (30°C) in late 1997 (A. Strong pers. comm.). This could have been responsible for the reduction in live coral (from 100 to 10% cover) along the southern and western reefs that was reported in a subsequent assessment (J. Maragos pers. obs.).

Coral bleaching as a factor impacting the condition of U.S. reef ecosystems has varied regionally and locally within reefs and among species. Generally

Figure 44. NOAA satellites track global "hot spots" where coral reef bleaching is likely to occur. In this map of the 1998 global bleaching event, places with elevated sea surface temperatures (SSTs) are marked in orange and red (Photo: NOAA/ National Environmental and Satellite Data and Information Series).



[54] The average elevation of the RMI is 7 ft. Even a moderate rise in sea level would probably eliminate some islands entirely and reduce the available area on others.

the shallower reefs are most affected. Except for shallow reefs off Florida, the CNMI, Palau, and Palmyra, mortality from bleaching episodes has generally been low. On the other hand, current marginal subtropical reefs where coral calcification temperatures are below optimum may not only survive, but benefit from global climate change (J. Maragos and D. Siciliano pers. comm.). Cooler water reefs off the NWHI and perhaps deeper reefs such as the Flower Garden Banks should be buffered from the effects of coral bleaching when surface waters warm.

Figure 45. Black-band disease devours a knobby brain coral over a one-week period (Photo: Andrew Bruckner).

Diseases

Where diseases have wreaked havoc – Florida, Puerto Rico, and the USVI – the coral reef managers consider disease a prime threat to reef health (Table 2).

Over the past two decades, there has been a worldwide increase in reports of disease affecting coral reef organisms. In the Western Atlantic, disease outbreaks have contributed to die-offs of seagrasses, corals, sea fans, sea urchins, sponges, fish, and other organisms. Disease has modified the structure and composition of reefs by removing common and locally abundant species. Indirect evidence suggests that disease outbreaks in marine environments are becoming more frequent (Harvell *et al.* 1999). Diseases are reported from Pacific reefs, but the incidence is lower than in the Caribbean (Work and Rameyer 2001).

Coral disease appears to be more prevalent near population centers. Changing environmental conditions from climate variability coupled with human impacts may weaken corals, making them more vulnerable to disease (Green and Bruckner 2000). Coral diseases have been recorded by 54 different nations, with most records (66%) from the wider Caribbean, including reefs in Florida, Puerto Rico, and USVI (Green and Bruckner 2000). Of 29 diseases reported in the literature, about 80% of the reports are for white-band disease, black-band disease, and white plague.

White-band disease has been the most significant cause of mortality to staghorn (*Acropora cervicornis*), elkhorn (*Acropora palmate*), and fused staghorn (*Acropora prolifera*) corals throughout the Caribbean. Their populations declined as much as 95% in the 1980s and early 1990s (Aronson and Precht 2000).

Black-band disease, first identified in 1972, occurs at low levels on most Western Atlantic reefs and may increase seasonally during warm periods (Fig. 45). Although black-band disease occurs worldwide, severe outbreaks have only been reported from the Caribbean, including U.S. reefs (Antonius 1973, Edmunds 1991, Kuta and Richardson 1997, Bruckner 1999).

White plague disease was first reported in the Florida Keys (Dustan 1977). A new, more virulent form (plague type II) emerged in the mid 1990s, and since then outbreaks have occurred in the Florida Keys, southwestern Puerto Rico, Culebra Island, and parts of the USVI (Bruckner and Bruckner 1997, Richardson 1998, Hernandez 2001, Miller *et al.* 2001). Particularly severe outbreaks were also observed in the spring and summer of 2001, impacting the important massive reef-building corals[55]. White plague may have severe impacts on reef ecosystems, as this disease affects a large number of coral species and kills tissue at rates up to 0.8 inches^2 a day (2 cm^2/day).

In a growing list of new coral diseases and other syndromes, yellow-blotch disease is of particular concern. This disease selectively infects slow-growing, massive corals, some of the most important reef-builders found on Caribbean reefs today. Once infected, the disease slowly kills the colony over several years (Green and Bruckner 2000).

In addition to scleractinian coral diseases, scientists have recently identified diseases and **pathogens** (disease-causing organisms) in colonial **anemones** and **soft corals** (soft-bodied sessile organisms that are in the same class as stony corals). Also, a fungus of terrestrial origin (*Asper-*

[55] Such species as the boulder brain coral (*Colopophyllia natans*) and the boulder star coral (**synonomyzed**, or renamed as one species, *Montastraea annularis*; some authors still recognize *M. faveolata* and *M. franksi*).

gillus) has caused tissue destruction, skeletal erosion, and in some cases, death of Caribbean sea fans (Smith *et al.* 1996). The pathogen may be coming from upland soils from the altered patterns of land use moving seaward during storms. This provides additional evidence for a link between disease and human activity.

An invertebrate disease decimated the long-spined sea urchin (*Diadema antillarum*) in the early 1980s (Fig. 46). In the Caribbean Sea and Western Atlantic, populations of mature urchins were reduced to around 3% of their original size (Lessios *et al.* 1984, Vicente and Goenaga 1984, Lessios 1988, Ritchie *et al.* 2000). Long-spined sea urchin populations have been slow to recover, possibly because remaining individuals are too far apart to ensure successful fertilization of gametes that are broadcast into the water (Levitan 1991). In some locations, particularly the shallow reef crests and fore-reefs, urchin numbers remain especially low, only about 1% of the pre-1983 levels.

Ecological impacts on the reefs from the die-off of the urchins have been profound. Urchins are herbivores, eating **macroalgae** (large attached algae or seaweed). After the die-off, there was a dramatic increase of algal cover, since grazing on the algae was much reduced. Some areas recovered better from this than others.

In the Flower Garden Banks National Marine Sanctuary, algal populations returned to prior levels within two years, perhaps due to an increase in other herbivores (Gittings and Bright 1986). But the rest of the Caribbean has yet to recover. For most U.S. reef ecosystems, the shift in coral-algal balance was further exacerbated by a die-off of elkhorn and staghorn corals. Once the coral died from other causes, algae took over.

Figure 47. Damage from Hurricane Andrew in Florida (Photo: NOAA).

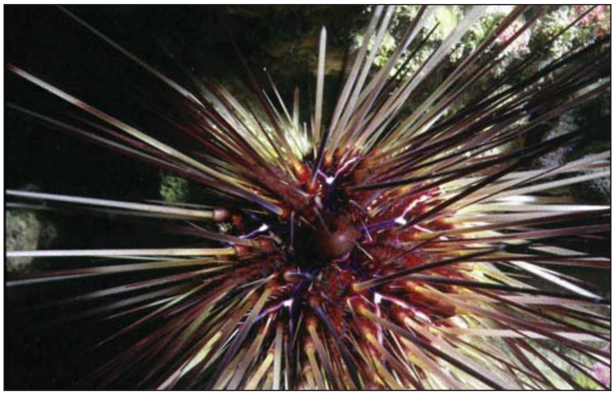


Figure 46. Long-spined sea urchin (Photo: Emma Hickerson).

Scheffer *et al.* (2001) postulated the shift from a healthy coral to a fleshy macroalgae-dominated system results from a combination of factors that make the system vulnerable to events triggering the shift. These factors include increased nutrient loading from land-based runoff and discharges and intensive fishing which reduces the numbers of large fish and subsequently the smaller herbivorous species (Aronson and Precht 2000, Scheffer *et al.* 2001). Once herbivorous fish became rare, the reefs rapidly became overgrown by fleshy brown algae. Scheffer *et al.* (2001) commented that this change will be difficult to reverse for two reasons: 1) mature algae are less palatable to herbivores and 2) algae-covered substrates prevent settlement of coral larvae.

Tropical Storms

With eight major hurricanes in the past 20 years nearly exterminating shallow-water *Acropora* coral populations, USVI managers consider tropical storms a major threat to their reef systems; another five managers from U.S. regions consider tropical storms a medium-level concern (Table 2, Fig. 47). If global climate change is underway and hurricanes occur with more frequency, then all the nation's managers have concerns that reefs would not have sufficient recovery time.

Reefs grow in areas subject to hurricanes and typhoons. In general, reefs have great structural resilience and recover from storms. There is also good evidence that that such disturbances help keep reef diversity high (Rogers 1993, J. Ogden pers. comm.). For example, sand and rubble keys and coral islets on atolls are notorious for forming and eroding during tropical storms, as fragments break loose and are deposited toward land or in

Figure 48. The shape of coral rock terraces in Guam reflect the dominance of encrusting and low profile growth forms (Photo: Ben Mieremet).

lagoons (Maragos *et al.* 1973). Hurricanes may also be beneficial because they fragment fast-growing branching corals that monopolize the substrate, freeing space for the slower-growing, massive species.

In the Caribbean and American Samoa, hurricanes make landfall on average every 15-20 years. But the CNMI and Guam are hit by about half the typhoons that develop in the Pacific because they lie in the Western Pacific monsoon trough. Guam has felt the impact of 52 major typhoons in the last 48 years. When typhoons pass nearby, the reefs receive the full impact of heavy wave action.

Contrary to what might be expected, typhoons in this region affect reefs to a lesser extent (Randall and Eldredge 1977) than hurricanes in the Caribbean (Tilmant *et al.* 1994) because the normal heavy wave action in the Pacific regularly removes the relatively fragile vertical branches. By doing this, the reef structure favors the encrusting or massive growth forms (Fig. 48). Typhoons, hurricanes, or cyclones have less impact on low-growing encrusting corals than they do on high-profile forms. Areas such as American Samoa and Palau, where storms are less frequent, have the higher-growing forms (Hubbard 1997).

Coastal Development and Runoff

Reef managers from nine regions consider coastal development, runoff, and sedimentation major threats to their coral reef ecosystems (Table 2). These areas include coral reefs off large continental population centers and close-to-shore reefs off urbanized islands (Fig 49). Near-shore reefs off high islands with relatively low human habitation[56] also experience substantial runoff and sedimentation during tropical storms.

In the United States, over 10.5 million people live in coastal counties and on islands near coral reefs, particularly in Florida, Puerto Rico, and much of the Main Hawaiian Islands. The Pacific Freely Associated States has another 203,000 island residents.

Infrastructure development is necessary to support coastal residents and the expanding reef tourism industry. This includes a myriad of activities: filling in wetlands to increase land area, dredging sand to replenish beaches, building causeways and bridges over existing reef habitats, dredging channels, erecting marinas and other support facilities along tidal shorelines, and destroying upland vegetation.

The impact of increasing human population on reef condition can be both acute and chronic. Reefs and related habitats suffer acute physical damage during construction, when such activities such as dredging to maintain deep-water draft for ships, erecting shoreside docks, and building marinas near or over coral reefs are in progress. The resulting runoff, plumes of sediment, and **turbid** (discolored, opaque) water from these activities can destroy a much broader area of reef habitat.

After coastal development is completed, the structures that were built and the activities related

Figure 49. The population of the Florida Keys has grown dramatically, resulting in increased development near or on coral reef ecosystems (Photo: NOS Photo Gallery).

[56] These include islands in American Samoa, CNMI, and the Freely Associated States.

[57] Agricultural pollutants include fertilizers, pesticides, herbicides, hormones, and antibiotics.

[58] Bases were built on Wake, Midway, Johnston, Palmyra, Howland, Jarvis, and Baker islands in the central Pacific. The Japanese established bases on Enewetak, Kwajalein, Chuuk, Yap, Peleliu, Koror, and other islands in the RMI and Caroline Archipelago.

to them often have chronic, long-term impacts. These include increased treated sewage effluent, water pollution from all the chemicals necessary to maintain boats and other apparatus necessary for tourists, and storm runoff from paved surfaces. There is also contaminant-laden runoff from industrial and agricultural[57] operations (Fig. 50). All degrade and can destroy sensitive reef, seagrass, and mangrove habitats.

Compounding these problems, deforestation and stripping vegetation on high islands for agriculture and housing results in extensive land and river run-off during rainstorms. Chronic turbidity and silt deposition smothers sessile invertebrates, creating biologically barren areas.

Large sediment plumes and turbid water from construction activities taking weeks or months to complete may substantially reduce the light to below the level needed for survival of coral reef plants for weeks or months. When water is turbid, light cannot penetrate as far down the water column, so the stony coral symbionts (the zooxanthellae) can only marginally survive, if at all, and coral bleaching results. Death of entire coral colonies may soon follow.

Besides runoff, there are additional concerns about seepage and current storm water control practices. Bacteria, disease, hormones, and other chem-icals in the water potentially alter coral polyp development, inhibit successful settlement onto solid substrate, and even impact the social, territorial, and feeding behaviors of other reef organisms. Wide variations in salinity that damage near-shore reefs could become more commonplace if global climate brings more storms and flooding.

Beaches erode from storms and natural wave action. Dredging to replace sand on bathing beaches is a most destructive activity. Silt from dredging activities buries corals and suffocates sensitive reef organisms. Replenishment degrades water quality during the operation. Not only costly, it affects everything within the areas where the sand is taken from as well as where it is deposited, and must be repeated every 5-10 years.

On some Pacific coral reef islands and atolls, coastal development has been influenced by their long history as strategic staging areas for national defense. In the late 1930s, the Japanese British, French, Americans, New Zealanders, and Australians began to fortify many islands in the central Pacific with garrisons, airfields, docks, and airplane refueling stations. All of these changed the structure of adjacent reefs (Woodbury 1946, Dawson 1959, Maragos 1993).

Bases were established on many islands[58]. While remnants of this construction remain, most reef populations have recovered. Battles and bombing raids during World War II also damaged reefs[59] (Maragos in Grigg and Birkeland 1997). Postwar reconstruction resulted in additional damage to reefs from dredging, filling, and causeway construction[60] (Brock *et al.* 1965, 1966). Ballistic missile testing at Johnston and Kwajalein stimulated additional construction, shore protection, and land reclamation (Maragos 1993, Smith and Henderson 1978).

Figure 50. Agricultural runoff can transport sediments, nutrients, and pesticides to coral reefs (Photo: NOS Photo Gallery).

Coastal Pollution

Optimum coral reef development is strongly correlated with clean, clear waters. Reef managers from eight jurisdictions consider coastal pollution (e.g., excess nutrients, toxic contaminants, and for the Marshall Islands, radiation) a high threat to their coastal ecosystems (Table 2).

The USEPA estimates that 60% of water pollution comes from **non-point sources** of contamination (input from a general area rather than a single point like a discharge pipe) such as storm-water runoff from urban areas and agriculture (Eichenberg 1999). More than 75% of the pollutants entering oceans are from non-point, land-based sources (YOTO 1998). Non-point pollution from

[59] At Chuuk, Peleliu, Enewetak, and Kwajalein, for example.
[60] At Majuro, Enewetak, Bikini, Tarawa, and Johnston islands.

Figure 51. Macroalgae overgrowing sea fans and several coral species (Photo: Brian Lapointe).

agricultural operations and elsewhere, urban runoff, and even atmospheric discharges of soot and toxic chemicals can impact the diversity of reef wildlife. Agriculture is the leading source.

Nutrification of near-shore waters is a problem for many reefs. High nutrient levels encourage growth of algae over coral (Smith *et al.* 1981, Maragos *et al.* 1985, Lapointe 1991, Fig. 51) and can create phytoplankton blooms that limit the sunlight stony corals need to survive.

Since 1972, industry and government agencies have spent more than $200 billion on reducing **point-source contamination** (specific points of discharge) – pipes dumping sewage and industrial pollutants and toxins directly into coastal waterways (Eichenberg 1999, Fig. 52). Harbors and urbanized, enclosed bays concentrate a wide variety of contaminants[61] (Hunter *et al.* 1995, U.S. Fish and Wildlife Service 1996, Green 1997).

Point-source pollution creates **hot spots** (relatively small contaminated areas) that impact shallow, near-shore coral reefs off Florida, Puerto Rico, the USVI, the Hawaiian Archipelago (e.g., O‘ahu, Midway, Kure), American Samoa, Guam, CNMI, and Palau.

The volume of human-related discharges from land-based activities, boating, and aviation has mushroomed, according to a recent report (Committee on Oil in the Sea 2002). Those authors calculated 29 million gallons of petroleum escape into North American waters each year from human activities. Of this, 85% are gasoline and oil spills involving land-based runoff from cars and trucks, fuel dumping by commercial airline pilots, and emissions from small boats and personal watercraft such as jet skis.

Although contaminants are a problem for coral reef ecosystems off urbanized areas, there has been little research on the fate or action of potential toxicants on reef species. One study conducted in Kane‘ohe Bay (Hawai‘i) by Peachey and Crosby (1995) shows the potential for unintended synergestic interactions between chemicals or classes of chemicals and other factors in the environment. In this study, when PAHs[62] in seawater are exposed to surface ultraviolet radiation from sunshine, these relatively unstable compounds become toxic and can kill crustaceans, polychaetes, and coral larvae. PAHs are common constituents of municipal wastes and urban runoff, particularly oils used in roadway pavement and gasoline products used in vehicles and airplanes. PAH toxicity has the potential to reduce overall reef biodiversity in harbors and wherever storm runoff from urban centers discharges directly into coastal waters.

Then there are radiation concerns. Between 1946 and 1958, the United States used Enewetak and Bikini Atolls in the Marshall Islands to test 67 nuclear devices (National Biodiversity Team RMI 2000). Both the physical blast and the radioactivity damaged the land and shallow lagoons. The Bravo blast in 1954 sent millions of tons of sand, plant, and sea life from Bikini reef, three nearby islands[65], and surrounding lagoon waters high into the air. Radioactive fission products, particle-activated products, and unspent radioactive fuel contaminated the debris. This radioactivity entered the aquatic environment of the atolls (Donaldson *et al.*

Figure 52. Point-source contamination in Chuuk, FSM (Photo: James McVey).

[61] Chemicals from such things as marinas, canals, harbors, boat anchorages, airports, and sewage disposal sites.
[62] Polycyclic aromatic hydrocarbons, a class of organic compounds found in petroleum products.
[63] Bokonijien, Aerokojlol, Nam

1997, Simon 1997, Walker *et al*. 1997, Robison and Noshkin 1999, Niederthal 2001). And atmospheric nuclear fallout rained on the inhabited atolls of Rongelap and Utirik, the uninhabited atoll of Rongerik, and other downwind atolls.

Figure 53. Recreational fishing and scuba diving are both popular activities that occur in coral reef areas (Photos: NOAA and Rusty Brainard).

Part of the U.S. government's radiological cleanup activities on Enewetak involved mixing part of the contaminated soil, mostly from Runit Island, with cement and submerging it in nearby Cactus Crater (formed by a nuclear explosion in 1958). The remainder of the soil was mixed with concrete and made into a dome above the crater. A non-contaminated concrete cap was then constructed over the dome. A National Academy of Sciences committee examined the dome and concluded that the containment structure and its contents presented no credible hazard to the people of Enewetak, either now or in the future (Noshkin and Robison 1997).

From the studies done to date, the RMI marine ecosystem is considered essentially recovered (N. Vander Velde pers. comm.). But the Marshall Islands land environment has not been totally restored, despite the government's cleanup. The U.S. Department of Energy advises people not to visit Runit Island or the northern islands, which remain too radioactive because they were not included in the cleanup effort focused primarily on the three southern islands (G. Johnson pers. comm.). The southern islands are now inhabited and used for growing food.

Figure 54. Waikiki Beach on O'ahu, Hawai'i is a prime tourist destination (Photo: NOAA Corps).

Tourism and Recreation

Over 75 million Americans engage in on-the-water activities (Lydecker and Podlich 1999, Leeworthy 2001). Recent data show over 90 million U.S. residents age 16 or older frequent coral reefs for some form of recreation (Leeworthy 2001, Leeworthy and Wiley 2001, Fig. 53). Over 11 million Americans participate in snorkeling or SCUBA diving, spending over 115 million person-days diving in U.S. coastal waters (Leeworthy and Wiley 2001). Many coral reefs in the United States and the Pacific Freely Associated States are heavily visited, particularly those along the shoreline and within easy cruising distances (Fig. 54).

With so many tourists visiting coasts and coral reefs, managers from the Main Hawaiian Islands consider the impacts from tourism and associated recreational activities a major threat to near-shore coral reef ecosystems, while managers from another seven jurisdictions consider it a medium concern (Table 2).

Damage to coral reef ecosystems from tourist activities is inevitable. Impacts range from coastal development (e.g., hotels, marinas) to boating and other recreational activities. Rental boats are a problem, as tourists unfamiliar with piloting vessels in and around shallow waters with coral reefs run aground or collide with corals. SCUBA divers, snorkelers, underwater tours using surface-supplied equipment, and a large number of personal watercraft (i.e., jet skis) have all affected reefs and water quality.

Harmful as they may be, damage from underwater reef-snorkeling tours and anchoring in most areas

Figure 55. Spearfishing is a common fishing technique that can negatively impact reef species (Photo: USAID).

is small when compared to natural disasters, sedimentation, pollution, and overfishing.

Fishing

A tremendous cultural and economic asset, a wide range of reef species are harvested from coral reef ecosystems for artisanal use, recreational enjoyment, and the commercial market. While too late for many of these ecosystems, managers and scientists now know that reef resources are not limitless and the capacity to harvest these species has been exceeded on most reef systems. Along with urbanization of coastal regions, non-point source pollution, and sedimentation from upland development, overfishing is a widespread factor that negatively impacts coral reefs (Fig. 55).

With the exception of the Flower Garden Banks National Marine Sanctuary, managers from the remaining 12 jurisdictions consider overfishing and gear impacts[64] a medium-to-high threat to the overall condition of coral reef resources (Table 2). Of particular concern to managers in Florida, Puerto Rico, USVI, Hawai‘i, and the offshore coral banks in the Gulf of Mexico, certain types of fishing gear, such as fish and lobster traps and large gill nets, have damaged reef fish habitats (Fig. 56). Illegal or inadvertent trawling over reefs or anchoring on the reef is also a concern.

Many desirable reef fish grow relatively slowly, mature later, and have irregular **recruitment** (the process whereby annual adult spawning activity produces sufficient young fish that mature into reproducing adults year after year). All of these make depletion more likely. Generally, the high-value resources – particularly lobsters, giant clams, large fish (groupers and snappers), and sharks – are removed first. To compound the problem, most reef fisheries in U.S. waters are small-scale, inadequately monitored and managed, and lack consistently enforced regulations.

Over 50% of all federally managed species of fish depend on coral reefs for at least part of their life cycle (USCRTF 2000). Unfortunately, many of these species have been greatly diminished by overfishing.

In 2000, 23 federally-managed reef fishes were listed as overfished in the South Atlantic, Gulf of Mexico, and the Caribbean[65]. Another 22 species of Atlantic sharks that visit or reside around coral reefs have been overfished (NMFS 2001). For this region, NMFS (2001) lists the status of another 58 species of South Atlantic reef snapper-groupers as unknown, 36 Gulf of Mexico reef-fish stocks as unknown, and 138 species of Caribbean reef fishes as unknown.

In the Pacific, reef fish fisheries are mostly managed within state and territorial waters. Although hard data were not available for this report, sharks, groupers, giant clams, bumphead parrotfishes (Fig. 57), humphead or napoleon wrasses, coconut

Figure 56. A snorkeler untangles a fish trap from a submersible's arm. These traps continue to catch marine life long after they are abandoned (Photo: OAR/NURP).

[64] These include trawling, dredging, and **ghost fishing** (a term for untended nets that can be miles in length, capturing fish, sea turtles, marine mammals, and diving birds as they drift along with the current).

[65] There are 14 South Atlantic species that are overfished: goliath grouper (*Epinephelus itajara*, formerly the jewfish), Nassau grouper (*E. striatus*), vermillion snapper (*Rhomboplites aurorubens*), red porgy (*Pagrus pagrus*), gag (*Mypteroperca microlepis*), red snapper (*Lutjanus campechanus*), speckled hind (*E. drummondhayi*), snowy grouper (*E. niveatus*), Warsaw grouper (E. *nitrigus*), golden tilefish (*Lopholatilus chamaeleonticeps)*, yellowtail snapper (*Ocyurus chrysurus*), red grouper (*E. morio*), black grouper (*M. bonaci*), and red drum (*Sciaenops ocellatus*). There are 6 Gulf of Mexico over-fished species: king mackerel (*Scomberomerus cavalla*), red snapper, red grouper, Nassau grouper, goliath grouper, and red drum. There are 3 Caribbean overfished species: Nassau grouper, goliath grouper, and queen conch.

crabs, and black-lipped pearl oysters, have been depleted throughout much of the Indo-Pacific region (J. Maragos pers. comm.).

Some reef species, like groupers and snappers, migrate great distances to specific spawning grounds and aggregate in unusually large numbers to reproduce. This makes them highly vulnerable because fishers know when and where they aggregate. For protection, a number of spawning aggregation areas in U.S. waters have been closed to fishing (e.g., one off St. Thomas Island, USVI in 1990, another within the fully protected Tortugas Ecological Reserve in 2001). Results indicate that protection of spawning aggregations is a sound management strategy for reversing impacts of overfishing.

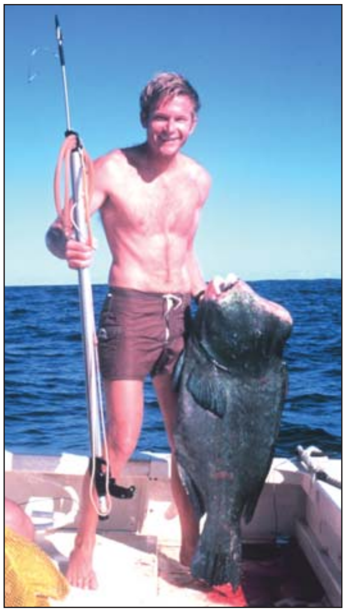


Figure 57. Bumphead parrotfishes, like this one caught in the 1970s, are now depleted through much of their range (Photo credit: NOAA).

During the 1970s, a spawning aggregation site for Nassau grouper off southern St. Thomas was overfished to complete collapse (Beets and Friedlander 1992). With that loss and evidence of a decline in a related species, a red hind (*E. guttatus*) spawning aggregation closure was implemented in 1990 off St. Thomas[66], based on a demonstrated decline in catch-per-unit-effort and average length of red hind. Red hind also showed a very skewed sex ratio, about 15 females per male (Beets and Friedlander 1992). A recent evaluation by Beets and Friedlander (1999) showed a significant increase in average size of red hind and great improvement in the sex ratio (approximately 4 females per male). There were also many large males.

Overfishing has resulted in four species of Western Atlantic groupers becoming candidates for listing under the U.S. Endangered Species Act[67]. Fishers in areas characterized by overfishing and **serial depletion** (harvesting the most desirable species until these are depleted, then overfishing the next most desirable species, and so on) eventually progress to catches of small herbivores like parrotfish and surgeonfish. This may moderate the socio-economic effects of overfishing high-value fishes, but at the same time it poses a new risk to reefs, as overfishing can change the ecological balance of the reef. Removal of predatory fish accelerates the **bioerosion** of corals (boring into, biting, or eating living tissue) by invertebrate prey. These invertebrates are held in check by predaceous fish. Overfishing has also been implicated as a primary cause for macroalgae overgrowing corals. When the herbivorous fish are removed, there is little to keep the fast-growing algae in check and the algae takes over.

Harvest and Trade in Corals and Live Reef Species

Most of the marine ornamental fish and invertebrates originating in U.S. waters come from reefs off Hawai‘i, Florida, Puerto Rico, and Guam. Managers from Puerto Rico, Hawai‘i, and RMI consider the trade in coral and live reef species a high concern, whereas managers from Florida, NWHI, and American Samoa consider it a medium threat (Table 2). In the Hawaiian Islands, some relatively rare species[68] are more common in the NWHI but considered to be vulnerable and inneed of protection.

The United States is the primary consumer of live coral for the aquarium trade as well as coral skeletons and precious corals for curios and jewelry (International Trade Subgroup 2000). Over a thousand tons (70-95% of the global trade) of hard corals and **live rock**[69], and 15-20 million coral reef fishes are imported each year for U.S. saltwater aquariums. This is increasing 10-30% each year.

Even though the United Stated is the largest importer of coral and live rock, the extraction of hard corals is prohibited or strictly regulated in most Federal, State, Commonwealth, and Territory waters because of widespread concerns these animals are vulnerable to over-exploitation. The CNMI permits coral collection for cultural purposes (production of lime). In Micronesia, live coral is collected and burned to create lime for

[66] Federal regulations were published in 1990 by the Office of the Federal Register at 50 C.F.R. Section 669.

[67] This law and implementing regulations are the authority for DoI and NOAA. They list those species that are deemed threatened or endangered by extinction for protection.

[68] Species such as the masked angelfish (*Genicanthus personatus*), dragon eel (*Enchelycore pardalis*), and the Hawaiian lionfish (*Pterois sphex*), now relatively abundant in some NWHI areas, require management to prevent over-exploitation.

[69] Removing living coral, chunks of reef substrate, and all the small plants and animals in these habitats for aquaria.

Figure 58. Seahorses are frequently targeted by the marine aquarium trade (Photo: Roberto Sozzani).

chewing betel nut[70], a widespread cultural practice in Palau, Yap, and other areas (J. Maragos pers. comm.). Additionally, coral and live rock can be collected for research purposes in most areas of the CNMI (M. Trianni pers comm.).

Over 1,000 species of marine fishes and invertebrates are traded. Particular species are targeted. For example, there is extensive trading in seahorses – at least 46 nations and territories including the United States (Fig. 58). The more than 20 million seahorses captured annually (Vicente 1996) are sold for the pet and curio trade and used in traditional medicines. Between 60-80,000 giant clams are traded internationally each year with over 70% destined for the United States. In recent years, however, most imported giant clams are small specimens that have been captive-bred for home aquaria.

Recent studies have shown that aquarium collectors have had a significant negative impact on the dominant reef species (Tissot *et al.* 2000). Part of the impact is how the fish are collected. For live capture, collectors often use cyanide and other poisons to stun reef fish, damaging their internal organs. It also kills other small fish, corals, and invertebrates not being collected.

Although cyanide fishing is generally not thought to occur in U.S. waters, other fish poisons including chlorine bleach, quinaldine, and plant toxins have been reported from Puerto Rico, Hawai'i[71], American Samoa, and one state in Micronesia. Use of quinaldine has been reported on reefs off Guam, and plant toxin use has been observed on reefs off the Freely Associated States (K. Foster pers. comm.).

Concerned about the impact of removing species and the methods of collection, the State of Hawai'i has designated Fisheries Replenishment Areas for the ornamental trade and is conducting related research in these and adjacent areas. The State of Florida imposed regulations on its 100-125 full-time aquarium fish collectors. These include license requirements, bag limits, minimum and maximum size limits, and allowable gear.

In the early 1990s, Puerto Rico exported as many as 200,000 reef fish and invertebrates each year. Ornamental organism collectors were not considered fishers, so this was unregulated until 1998, when a new law was issued that required collectors to obtain permits. At the present time, ornamental collection and exportation is the subject of litigation and controversy. Reliable information is scarce, data on exported invertebrates is unavailable, and the number of full-time and part-time collectors is unknown. Currently, only eight exporters have been identified with a reported total catch of 82,290 reef fish from 92 species (Ojeda-Serrano and Aguilar-Perera 2001). The first stage of an in-depth study of this industry will be completed by October 2002.

Boats, Ships, and Groundings

Over 23 million Americans over 16 spend 290 million boating days in coastal waters (Leeworthy and Wiley 2001). With 16.8 million boats nationwide, recreational vessels comprise America's largest fleet (Lydecker and Podlich 1999), with most activity in near-shore ocean waters. There is particularly heavy use over shallow coral reefs near urban centers, such as those off Florida, Puerto Rico, the USVI, Hawai'i, and Guam. Therefore, managers of shallow coral reef systems off

Figure 59. One of the many boats that have grounded in the Florida Keys (Photo: FKNMS).

[70] Live coral is preferred because it tastes better than dead coral that has been invaded by algae, sponges, and other organisms.
[71] Use of chlorine for fishing has been substantiated by court cases in the last couple years (D. Gulko pers. comm.).
[72] For example, Miami, Port Everglades, Palm Beach, Florida; San Juan, Puerto Rico; Honolulu, Barbers Point, Pearl Harbor, Hawai'i; Pago Pago, American Samoa; and Apra Harbor, Guam.

Figure 60. Grounded Taiwanese longliner on Rose Atoll (Photo: Jim Maragos, USFWS).

Florida, the USVI, the Main and Northwestern Hawaiian Islands, and FSM consider recreational boating a serious issue (Table 2).

Boat traffic threatens reef structure and associated wildlife. Propellers speeding through shallow waterways have broken corals, scarred seagrass beds, and killed endangered marine mammals and sea turtles. Groundings and anchor damage are considered some of the most destructive chronic human factors, causing significant localized damage to shallow-water coral reefs (Precht 1998).

Coral reef damage associated with ship groundings includes the direct loss of corals and other benthic invertebrates when they are dislodged, fractured, and crushed. Groundings also increase the risk of contamination from oil and toxic chemical spills.

Large ports located near shallow-water reefs[72] with heavy traffic increase the probability of vessel collisions with reefs. Also, ships from foreign ports can introduce alien species into coastal waters[73].

Over the past decade, moderate to severe large vessel groundings have occurred. In the Caribbean, a number of groundings severely damaged the reef structure off southeastern Florida, Puerto Rico, and the USVI (Fig. 59). For more information on groundings and their impacts, see the jurisdictional reports following the National Summary.

Figure 61. Plastic marine debris on a Florida coral reef (Photo: William Harrigan).

In the Pacific, the U.S. Coast Guard (USCG) reported 48 ship groundings in Hawai‘i between 1993-1996, including passenger and fishing boats, freighters, towboats, and industrial, military, and offshore supply vessels. In the NWHI, a fishing vessel grounded in 1999 at Kure and another in 2000 at Pearl and Hermes Atoll. In American Samoa nine longline-fishing vessels were blown onto a reef in Pago Pago Harbor during a hurricane in 1991, and in 1993 another longliner ran aground on Rose Atoll (Fig. 60). In addition, several other fishing vessels, yachts, and a tugboat grounded on other Samoan reefs. In Guam, there were at least 15 groundings and 13 sinkings between 1992 and 1996, including a research vessel. In 1999, another passenger vessel attempting to land illegal immigrants at Guam ran aground on the reefs of the Guam National Wildlife Refuge.

Marine Debris[74]

All sorts of material is discarded from boats and vessels (Fig. 61). Currents transport some of this debris long distances and wave action washes it back and forth across shallow coral reefs, ultimately depositing it along shorelines. Marine debris is considered a medium-to-high threat by the coral reef managers in Florida, Puerto Rico, the Hawaiian Islands, particularly the NWHI, the CNMI, the U.S. remote **insular** (island) reefs, the FSM, and Palau (Table 2).

In the NWHI, derelict fishing nets from commercial fishing activities far away in the North Pacific have had a major impact on shallow reef systems, dislodging and breaking coral colonies. They also entangle Hawaiian monk seals[75] and other marine mammals, sea turtles, corals, fish, and seabirds, often killing them. Exotic species attached to drifting marine debris can be transported far from their place of origin and introduced to remote reefs.

Some of the largest marine debris (e.g., planes, ships, and tanks) on Pacific islands and in lagoons date back to World War II battles and

[73] One example: the elephant ear sponge (*Ianthella basta*), a resident of New Guinea and Indonesian reefs, is now an established alien species in Guam’s Apra Harbor.

[74] Fishing gear and other remnants of human activities coming from recreational and commercial vessels, storm drains, industrial facilities, and waste disposal sites.

[75] In 2000, about two dozen endangered Hawaiian monk seals were found entangled in nets off NWHI islands and atolls (R. Brainard pers. comm.).

bombing raids. They are now designated historical parks and monuments or are popular dive sites and artificial reefs (Fig. 62).

Removing marine debris is a major task. To date, 132 tons[76] of debris have been removed out of an estimated 1,000 total tons encountered on NWHI reefs and beaches (R. Brainard pers. comm.).

Figure 62. Sunken debris from World War II in Chuuk Lagoon, FSM (Photo: Tim Rock).

Alien Species

Alien species, along with their associated symbionts and diseases, have had devastating effects on native biota globally. In the United States, Hawai'i has been impacted the most. Managers of Hawaiian Island and RMI land and marine resources consider alien species to be one of the greatest threats to native wildlife and habitats, whereas managers from five other jurisdictions consider alien species a medium priority (Table 2).

Wagner *et al*. (1990) reported Hawaiian terrestrial habitats now contain more alien species than native ones. On both land and sea, a spectacular number of invasive species have become established throughout the islands.

Some 19 species of marine macroalgae have been introduced to Hawaiian coastal waters since 1950, four of which have been highly successful. Recent studies have shown overgrowth and killing of coral by an alien red alga (a species of *Kappaphycus*) in Kane'ohe Bay, O'ahu. This alga is thought to have caused the shift from a predominantly multi-species coral habitat to a monoculture algae habitat in some areas of the bay (Woo 2000). This may affect everything from fish recruitment to trophic interactions and have widespread impacts such as commercial fishing and tourism.

Figure 63. Sea turtle swimming through an invasive algal bloom (Cladophora) in Honokowai, West Maui (Photo: Ursula Keuper-Bennett and Peter Bennett).

Two invasive algae, a brown and a green alga (*Hypnea musiformis* and *Cladophora sericea*), are overgrowing reef corals off western Maui (Fig. 63). These develop into algal blooms and are displacing native and endemic algae. More significantly, the algae being replaced are the primary food for the threatened green sea turtle and provide critical habitat for the endangered hawksbill sea turtle (Gulko in press).

Over 250 species of marine invertebrates have been introduced into Hawaiian waters (Eldredge and Englund 2001). The effect on coral reefs for most of these has not been documented. Alien sponges however, have been observed growing over corals in Kane'ohe Bay, O'ahu, and concerns have been raised about the introduced snowflake coral (*Carijoa riisei*) competing with shade-adapted corals in some areas (L. Eldredge pers. comm.).

Thirty-four species of marine fishes have been introduced into Hawaiian waters; not all are successfully established. Of the established species, 13 species were intentionally released and at least seven species were accidental introductions (Englund and Eldredge 2001).

NOAA, the Hawai'i Department of Land and National Resources (DLNR), USFWS, National Park Service (NPS), the U.S. Geological Survey (USGS), the Bishop Museum, the University of Hawai'i, and other partners initiated a Hawaiian Pilot Study in 2001 to list all coastal marine species (native and alien) and build an early warning system for invasive and alien species.

Other Physical Impacts to Coral Reefs

Besides the environmental pressures on reef ecosystems already mentioned, there are other types of direct physical impacts to reef structure. Activities involving explosives or heavy machinery near coral reefs can damage these fragile, living ecosystems. Although not legal in U.S. coastal waters, dynamiting reefs has been used to collect fish. In the CNMI, dynamite fishing using WWII ordnance was prevalent in the past, but this practice appears to be nonexistent today. Elsewhere in the Indo-Pacific, however, there is evidence this practice continues (Fig. 64).

Not all the war-time relics mentioned in the discussion of marine debris are safe. In 1996, the CNMI Governor asked the U.S. Navy to detonate live depth charges found on a wrecked WWII Subchaser, as they posed a hazard to recreational divers

Figure 64. A diver swims past corals broken by dynamite fishing (Photo: Nancy Daschbach).

and fishermen (Worthington and Michael 1996). Although the force of the detonation damaged reef structure at the popular Coral Gardens dive site and a nearby fish reserve, killed wildlife, and created an extensive sediment plume, those reefs are now safe (Trianni 1998).

Managers from Puerto Rico and the Commonwealth of the Northern Mariana Islands where active security training exercises are being conducted, expressed high concern about the impact of bombing and live-fire activities on coral reefs. Managers from the Hawaiian Islands, where there were such activities in the past have moderate concerns for the condition of nearby reefs (Table 2).

DoD Military Services (i.e., the Air Force, Army, Navy, and Marine Corps) generally avoid coral reef areas in their normal operations except for some mission-essential ashore and afloat activities (DoD 2000). Wherever possible, it is DoD's policy to avoid adversely impacting coral reefs during training exercises. At military installations, the Services work to minimize activities that may negatively impact coral reef ecosystems.

To ensure that its Puerto Rico operations and training exercises do not negatively impact coral reefs and other marine resources, the Navy is cooperating with the USGS Biological Resources Division to update mapping coral reefs and seagrass beds near Naval Station Roosevelt Roads, Isla Pineros, Cabeza de Parro, and Vieques.

In the CNMI, the Navy considers its bombing range at Farallon de Medinilla a vital asset for the continued security training exercises for military readiness missions. To monitor the condition of the reefs, annual marine surveys are conducted by scientists from NOAA, the USFWS, and the CNMI Division of Fish and Wildlife Division of Environmental Quality. From those surveys, the Navy has concluded that there have been no significant impacts on marine communities, endangered and protected species, fishery resources, and existing coral (DoD 2000).

Offshore Oil and Gas

Only a small fraction (8%) of all the petroleum escaping into North American ocean waters is from pipeline ruptures or massive tanker spills – a total of 2.7 million gallons (Committee on Oil in the Sea 2002). An even smaller amount (3%) is from offshore oil exploration and extraction activities. Fortunately, no major oil spills or other incidents off the reefs of the United States or the Pacific Freely Associated States have occurred.

Only the managers of the Flower Garden Banks National Marine Sanctuary have expressed moderate concern over offshore oil and gas threats to coral reef systems in the near future (Table 2). Protective measures enacted by the Minerals Management Service (MMS) have been successful so far in minimizing impacts from this activity around the Flower Garden Banks National Marine

[76] This number includes debris collected by the annual multi-ship (i.e., NOAA ship *Townsend Cromwell*, the USCG Cutter *Kukai*, and others) cleanup efforts conducted throughout the NWHI from 1999 through 2001.

Sanctuary. In spite of the intense activity, long-term monitoring studies indicate no significant detrimental impact to the coral reefs from nearby oil and gas development (Gittings 1998).

Petroleum production from offshore Federal lands presently comprises 20% of domestic oil production and 27% of domestic natural gas production (Kelly 1999). Most of this is centered in the northern Gulf of Mexico. It is one of the most active areas for oil and gas exploration and development in the world.

By the end of 1995, approximately 5,000 prodution platforms had been installed, 32,000 wells drilled, and over 30,000 mi of pipeline installed (Deslarzes 1998). This activity on the Gulf of Mexico Continental Shelf waters and the nearby land also have oil refineries, storage facilities, and shipping lanes frequented by oil tankers.

Potential impacts from offshore oil and gas exploration and development include accidental spills, contamination by drilling-related effluents and discharges, anchoring of vessels on coral reefs, seismic exploration, use of chemical dispersants in oil spill mitigation, and platform removal. About 1,000 of the platforms have already been removed, and another 1,000 platforms will need decommissioning in the coming decade (Kelly 1999).

Figure 65. The High Island 389 natural gas platform is located one mile east of the East Flower Garden Bank (Photo: Frank and Joyce Burek).

For the United States, 72% of the oil and 97% of the natural gas produced in offshore U.S. waters comes from the northwestern Gulf of Mexico (MMS 2002). Within a 4 nmi radius of the Flower Garden Banks National Marine Sanctuary there are 10 production platforms and approximately 100 mi of pipeline. Half of the pipeline is dedicated for oil (Deslarzes 1998). And there is one gas production platform (High Island 389A, Fig. 65) located within the boundary of the East Flower Garden Banks.